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Bioenergy

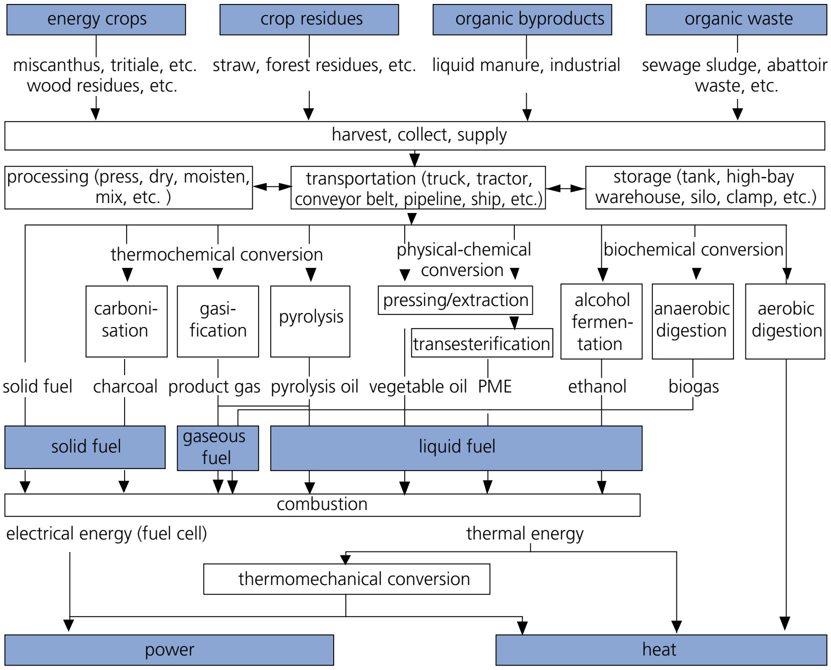
Related topics

- Renewable resources
- Automobiles
- Fossil energy
- Agricultural engineering
- Process technologies

Principles

Bioenergy is obtained from biomass. The term biomass encompasses all materials of biological (organic) origin, i. e. plants as well as animals and the resulting residues, byproducts and waste products (e. g. excrement, straw, sewage sludge). In chemical terms, biomass consists of carbon (C), oxygen (O) and hydrogen (H) plus various macro and microelements (such as nitrogen, potassium, chlorine).

The biomass that can be utilised to generate bioenergy originates primarily from agriculture and forestry, and the various biomass-processing industries downstream. Other more dispersed sources include grass cuttings from roadside maintenance, organic residues from milk processing, and the organic fraction of household waste. Not all of this biomass is available for producing energy, however. Only the biomass left over after the demand for food and animal fodder has been satisfied, and the demand for biomass as a raw material for use as industrial feedstock (e. g. for timber derivatives, pulp and paper, bioplastics, cosmetics) has been met, can be used as an energy carrier. Certain plants can also be grown specifically as energy crops on land not required any longer for the production of food and/or animal fodder.


energy crops
crop residues
organic byproducts
organic waste
miscanthus, tritiale, etc. wood residues, etc.
straw, forest residues, etc.
liquid manure, industrial
sewage sludge, abattoir waste, etc.
harvest, collect, supply
processing (press, dry, moisten, mix, etc.)
transportation (truck, tractor, conveyor belt, pipeline, ship, etc.)
storage (tank, high-bay warehouse, silo, clamp, etc.)
thermochemical conversion
physical-chemical conversion
biochemical conversion
carboni-sation
gasi-fication
pyrolysis
pressing/extraction
transesterification
alcohol fermen-tation
anaerobic digestion
aerobic digestion
solid fuel
charcoal
product gas
pyrolysis oil
vegetable oil
PME
ethanol
biogas
solid fuel
gaseous fuel
liquid fuel
combustion
electrical energy (fuel cell)
thermal energy
thermomechanical conversion
power
heat

Range of options for producing energy from biomass (fields shaded in blue: energy sources, fields without shading: conversion processes). The various biomass fractions first have to be gathered up and delivered to a conversion plant. The main steps involved, where relevant, are harvesting, transportation, mechanical processing and/or storage. The biomass can then be converted into solid, liquid and/or gaseous secondary energy carriers for a broad variety of possible uses (so-called biofuels) using thermo-chemical, physical-chemical or bio-chemical conversion processes. Straw, for example, first has to be brought in from the field, pressed into bales, and transported to the processing site. There, if necessary after being placed in temporary storage, it can be used to produce a synthesis gas for subsequent conversion into methane suitable for use as an engine fuel in the transportation sector. Alternatively, the straw can be saccharified and then converted into bioethanol using a bio-chemical process. In this case too, the product is suitable for use as an engine fuel. Source: DBFZ 2007

Seen on a global scale, biomass could potentially make a significant contribution towards meeting the given energy demand, from an energy-management point of view. Estimates range between 20% and over 100% of present levels of primary energy consumption, depending on the anticipated yield of various energy crops and the availability of additional arable land not needed for food and fodder production. (in comparison, the current share of biomass used to cover global demand for primary energy lies at around 10%.) It is foreseeable that Western industrialised countries will be able to increase the land area available for growing energy crops – and hence the biomass yield – as a result of enhanced methods for the production of improved plants for food and fodder. Such improved plants will allow increasingly higher yields to be obtained on less land in the future. By contrast, the potential volume of residues, byproducts and waste products is likely to remain constant.

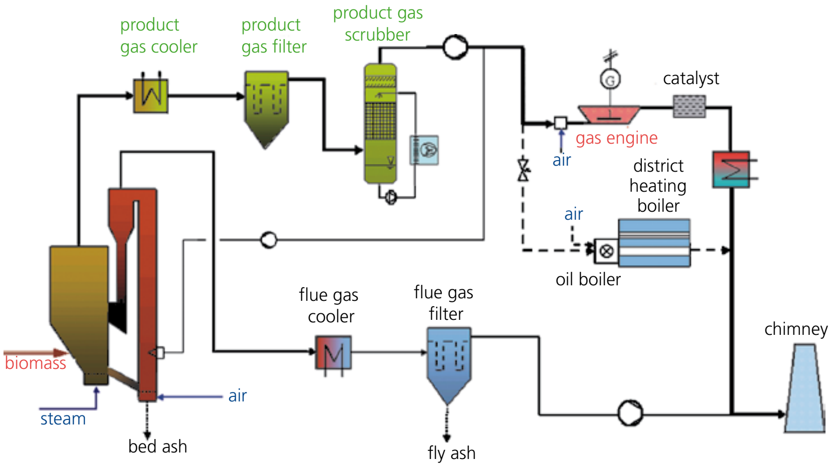
Bioenergy is generated in a multistage supply chain that starts with the collection of residues, byproducts or waste or the cultivation of energy crops. This biomass then undergoes a variety of processing, storage and transportation steps and industrial conversion processes to produce the secondary energy carriers or biofuels, which can be used to meet the given demand for different forms of useful energy. There are numerous processing options for biomass, involving different conversion routes.

▶ **Thermo-chemical conversion**. Biomass can be converted into useful energy or into secondary energy carriers using processes based on heat. In such conversion processes, solid biofuels are mixed with an oxidising agent (e. g. air, water) below the stoichiometric concentration under defined conditions (pressure, temperature, etc.). This enables them to be converted into solid, liquid and/or gaseous secondary biofuels. All processes of this type are based on the same fundamental thermo-chemical reactions, but the composition of the resulting secondary biofuel varies depending on the selected process parameters and the type of biomass involved:

- In *gasification*, the solid biofuels are converted as completely as possible into an energy-rich producer gas or synthesis gas and thus into a gaseous energy carrier. After several cleaning processes, the gas can be burnt directly without any further chemical transformation, e. g. in an engine to provide heat and/or electricity, or undergo a subsequent synthesis process to be converted into a liquid or gaseous transportation fuel with defined properties (e. g. Fischer-Tropsch diesel, synthetic natural gas (biomethane), hydrogen).
- In *pyrolysis*, solid biomass is converted solely by the (short-duration) application of heat into solids (charcoal), liquids (bio crude oil), and gases. The aim of this conversion process is to obtain a maximum yield of liquid components. The byproducts, i. e. combustible gases and solids, can be used to provide e. g. the process energy. The resulting pyrolysis oil or bio crude oil is refined and can be utilised either as feedstock for the chemical industry and/or as liquid fuel for engines and/or turbines.
- In biomass *carbonisation*, the solid biofuel is converted through the application of heat on the basis of the same thermo-chemical reactions in such a way as to maximise the yield of solid carbon (i. e. charcoal), which can then either be used as an industrial feedstock (e. g. activated charcoal for filters) or as a source of energy (e. g. for leisure activities).

► **Physico-chemical conversion**. This method is used to produce liquid biofuels from biomass containing oils and fats (e. g. rape seed, sunflower seed). The oil is separated from the solid phase e. g. by mechanical pressing and/or extraction. The vegetable oil can be used as an energy source both in its straight form and, after conversion (i. e. transesterification with methanol), as FAME (fatty acid methyl ester or biodiesel). Both vegetable-oil-based liquid fuels are ready for market as far as the transportation sector is concerned, but only FAME has gained broader market significance so far.

► **Bio-chemical conversion**. In this method, the biomass is broken down by microorganisms, and hence its conversion is based on biological processes.



Thermo-chemical plant for the gasification of biomass and the generation of electricity from the resulting producer gas: The solid biomass is gasified with steam in a reactor to produce a medium calorific value (MCV) gas that, at this stage, is contaminated with tar and dust. The MCV gas is then cooled down. After this, the tar and dust are removed in a two-stage cleaning process to meet the prescribed specifications for its use as engine fuel. The energy required for the gasification process is obtained by burning the charcoal produced as a waste product of the gasification process itself. Finally, the filtered and scrubbed MCV gas is fed to a CHP unit (i. e. gas engine) to generate electricity and heat. Source: repotec Vienna 2006

- In alcohol fermentation, the sugar, starch and cellulose contained in the biomass is transformed into ethanol which, after distillation and dehydration, can be employed as pure alcohol or blended with conventional gasoline to fuel engines and/or turbines.
- In anaerobic *fermentation*, organic matter is converted into biogas (roughly 60% methane and 40% carbon dioxide) by microorganisms. This gas can be used in combined heat and power (CHP) generating stations to produce electricity and heat, or alternatively, after further processing, upgrading, and where necessary distribution through the existing natural gas pipelines, used to fuel vehicles that run on natural gas.
- Other bio-chemical conversion options currently under discussion include the production of bio-oil (known as algae or algal diesel) or hydrogen with the aid of microscopic algae.

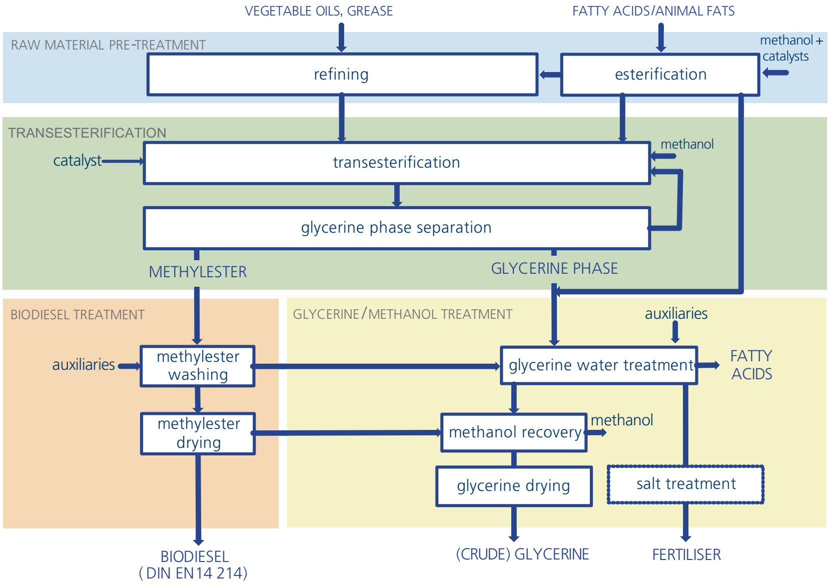
Applications

► **Solid biofuels**. Solid biofuels (e. g. wood logs, wood chips, wood pellets) are the “original” biofuels most widely used throughout the world. Such solid biofuels are produced with a broad variety of processes characterised by widely differing degrees of mechanisation. For the provision of heat and/or electricity, such fuels can be used in fireplaces, furnaces, and other combustion devices with all thermal capacities demanded on the market. The biggest share of these solid biofuels in current use to cover the given energy demand is employed in private households for the provision of heat in small-scale heating devices. Especially the use of wood pellets has been gaining in popularity in recent years. In Central Europe this is particularly true for domestic heating systems operated on a very small scale (i. e. often below 15 kW thermal capacity).

Pellet-burning central-heating furnace: The wood pellets in the storage tank (right) are conveyed to the combustion tray at regular intervals under fully automatic control, passing through a rotating feed unit with a screw conveyor. During the combustion process, the flow of primary air to the combustion tray and of secondary air into the combustion chamber located above the tray is precisely controlled, to ensure that the fuel is completely burned. The hot flue gases from the combustion chamber are conducted through heat exchangers where they transfer their thermal energy to the heating medium. Ash from the combustion of the wood pellets falls into a box below the reaction vessel, which needs to be emptied at regular intervals. Source: paradigma 2007

In the meantime, European standards have been introduced for the use of wood pellets as a heating fuel. This combined with modern pellet burning technology allows highly efficient furnaces to be operated fully automatically and to be characterised by very low airborne emissions (especially emissions of particulate matter).

In terms of combustion efficiency, wood's low ash content and favourable chemical composition make it a highly suitable candidate for use as a solid biofuel. Compared to this, the combustion of straw and other herbaceous biomass fractions is more challenging due to their comparatively low ash softening point (the temperature at which the ash becomes fluid and therefore starts to bake onto the walls of the combustion chamber or the surface of the heat exchanger elements). Such non-woody solid biofuels also often contain a high proportion of undesirable trace elements (such as chlorine), which can have an elevated corrosive effect and/or lead to the release of highly toxic airborne pollutants. These unfavourable properties are the reason why solid biofuels derived from herbaceous plant material have not so far been used to any greater extent in small-scale as well as in large-scale combustion plants.

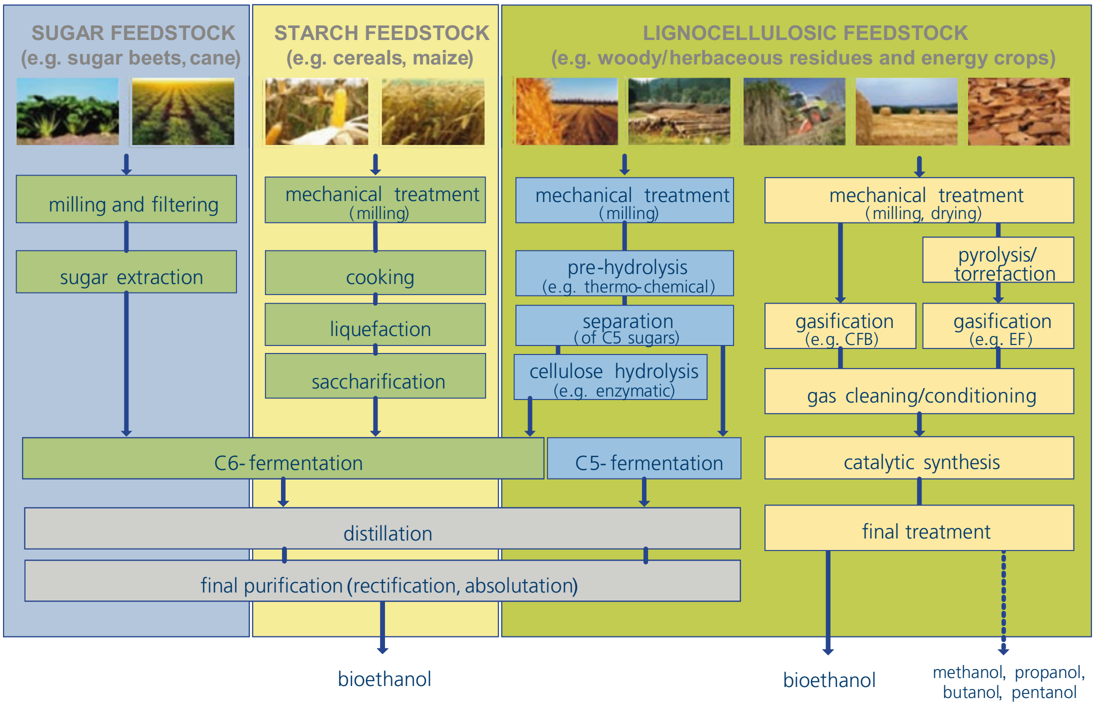


Production of biodiesel from colza oil: The vegetable oil is converted into fatty acid methyl ester (FAME) or biodiesel by transesterification, a process in which the triglyceride molecules in the vegetable oil are split open by a catalyst, and methanol is added to produce monoesters of fatty acid and glycerin. The resulting FAME is then purified and, if necessary, conditioned/winterised. It can then be used as a direct substitute for fossil diesel fuel. In parallel the glycerin is cleaned to be sold on the market.

Power generation from wood in district heating or *combined heat and power (CHP)* plants has so far mostly been based on conventional steam processes and thus forms part of normal power-plant engineering practice. This type of power generation in plants with an output of 2 MW and above is market-mature and widely used within the global energy system. By contrast, methods of generating electricity or combined heat and power from solid biofuels in plants with a capacity in the kW range are still at the development stage. Such plants nevertheless offer the possibility of opening up new applications in the context of decentralised power generation (e. g. combined heat and power generating plants for public swimming pools or schools, for small district heating systems, or for large farming complexes).

In a district heating plant fueled by solid biofuels, the biomass is combusted for example on a grate. The fuel loader deposits the wood fuel on this grate through which primary air and in some plants additionally recycled flue gas is blown from below. This supply of air serves firstly to drive out the residual moisture in the fuel, and subsequently to assist with its pyrolytic decomposition and gasification as well as with its partial combustion. The combustion gases rising up from the moving bed are fully oxidised in the hot burning chamber located above the grate with the addition of secondary air. The hot flue gases are conducted through the steam generator and subsequently fed to the flue gas treatment unit where in most cases only dust is removed to fulfil the given emission regulations. The steam generated by the process is depressurised in a turbine and used to supply district heat.

► **Gaseous biofuels**. Gaseous fuels of biogenic origin can be used in gas-fired heating devices for heat provision and for the combined generation of power and heat in gas engines, turbines, and certain types of fuel cell, including those used to power road vehicles. After processing the gaseous fuel to obtain a quality comparable to natural gas, this biofuel can be fed into the natural gas distribution network. Consequently, the fuel is available for use not only at the site of the conversion plant but also at any other site connected to the existing natural gas supply infrastructure. Alternatively, the gas can be transformed into a liquid secondary energy source (e. g. methanol).


SUGAR FEEDSTOCK
(e.g. sugar beets, cane)
STARCH FEEDSTOCK
(e.g. cereals, maize)
LIGNOCELLULOSIC FEEDSTOCK
(e.g. woody/herbaceous residues and energy crops)
milling and filtering
sugar extraction
mechanical treatment (milling)
cooking
liquefaction
saccharification
mechanical treatment (milling)
pre-hydrolysis (e.g. thermo-chemical)
separation (of C5 sugars)
cellulose hydrolysis (e.g. enzymatic)
mechanical treatment (milling, drying)
pyrolysis/ torrefaction
gasification (e.g. CFB)
gasification (e.g. EF)
gas cleaning/conditioning
C6-fermentation
C5-fermentation
catalytic synthesis
distillation
final treatment
final purification (rectification, absolutation)
bioethanol
bioethanol
methanol, propanol, butanol, pentanol

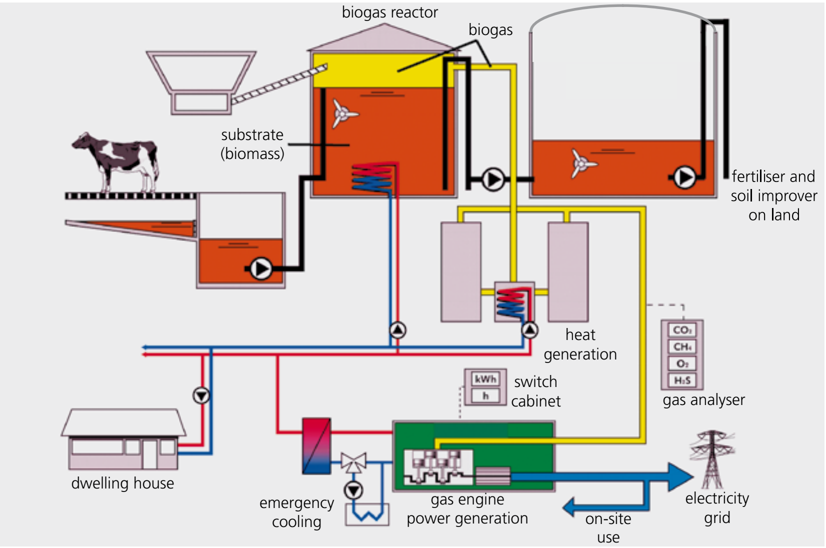
Possible ways of producing bioethanol from biomass: Basically all pathways to produce bioethanol based on bio-chemical conversion include the process steps of fermentation (i. e. converting sugar to ethanol), distillation (i. e. separating ethanol and stillage), and purification (i. e. to provide pure ethanol). If biomass containing sugar is used as a feedstock (e. g. sugar beet, sugar cane), an additional step is required to remove the sugar from the biomass to improve the efficiency of the bioethanol production process. If the ethanol production process is based on starch extracted from a cereal crop, additional liquefaction and saccharification stages are needed to allow the microbes to convert the biomass into bioethanol. Similar conditions apply to the use of celluloses as a feedstock. Here too, a technologically demanding saccharification stage is needed, e. g. based on hydrolysis. An alternative method involves converting the celluloses into synthesis gas using thermo-chemical gasification, and further processing the output by a catalytic synthesis into bioethanol. Source: DBFZ 2008

A number of very different techniques and processes are available to produce biogenic gaseous fuels.

- State-of-the-art bio-chemical biomass conversion plants for the production of biogas (i. e. biogas plants) typically have an electrical output ranging between tens or hundreds of kilowatts and several megawatts. They are usually designed to process organic residues, byproducts and waste (e. g. liquid manure, the organic fraction of household waste, sewage sludge) and/or energy crops (e. g. corn silage). In most cases, the resulting biogas is used to generate electricity in combined heat and power (CHP) plants (i. e. gas engines). But the produced biogas can also be upgraded to natural gas quality, fed into the natural gas distribution network and used, e. g., in the transportation sector as so-called “green” gas.
- Thermo-chemical plants for the production of producer gas from solid biofuels and the use of this gas for the generation of heat and/or electricity exist at present in the form of demonstration and/or pilot plants only. The advantage of such gasification plants compared to ordinary combustion units is their theoretically higher conversion efficiency to electrical energy. The downside is that such gasification-based conversion devices require a fairly complex technology that is only on the brink of commercialisation so far and thus characterised by relatively high risks. As an alternative and/or supplementary solution to the direct conversion of the product gas into heat and/or electrical energy, it is also possible to convert the producer gas to obtain a gaseous secondary energy carrier with defined properties. One example involves converting the gas into biomethane (synthetic natural gas or Bio-SNG) that meets natural gas quality specifications. This Bio-SNG can then be fed into the natural gas distribution network and used in the same way as natural gas, e. g. within the transportation sector.

▶ **Liquid biofuels**. Liquid biofuels are used as fuel for road vehicles or in (small-scale) CHP units. The energy sources in question are:

- Vegetable oil derived from e. g. rape seed or oil



Biogas plant: The main components of the plant are the fermenters (top), in which microorganisms convert the substrate (brown) into biogas (yellow) in the absence of oxygen. The resulting biogas is cleaned and used in a combined heat and power (CHP) generating unit (i.e. gas engine, green). Most of the electricity is fed into the utility grid, while the provided heat is used locally. The fermented substrate is subsequently spread as fertiliser /soil improver on arable land. Source: Modified according to FNR 2006

palms can be used as a heating or engine fuel in addition to its more familiar uses as a food and fodder ingredient and as feedstock for a multitude of industrial products (e.g. cosmetics, paints and varnishes, lubricants). However, due to the variations in quality typical of natural products, and the differences with respect to today's conventional diesel fuels, vegetable oil is only being used at present to a very limited extent in suitably modified CHP plants, and to an even lesser extent as fuel for vehicles driven by internal combustion engines.

- Fatty acid methyl ester (FAME, *biodiesel*) is obtained from vegetable oil through the process of transesterification. The result of this process is a fuel with properties that are largely equivalent to those of conventional diesel fuel, depending on the type of vegetable oil employed. The main use of such FAMEs is therefore as a diesel substitute or diesel additive (i.e. FAME is blended with diesel derived from fossil fuels). The latter application is significantly growing in importance on a global scale.
- *Bioethanol* – in addition to its uses as a chemical feedstock and as a food (i.e. an ingredient in certain beverages) – is produced from biomass containing sugar, starch, or celluloses. The production of ethanol from sugar or starch is a centuries-old technique. This is not true for cellulose-based feedstock due to existing technological challenges relating particularly to the conversion of cellulose into sugar. Bioethanol can be used both as an additive blended with conventional petrol and in its pure form in suitably adapted engines. Both of these applications have already been commercialised (e.g. in Brazil). Alternatively, ethanol can be converted into ETBE (ethyl tertiary butyl ether) and blended with fossil-derived petrol as an additive.
- Synthesised gaseous or liquid engine fuels (e.g. Bio-SNG, hydrogen, methanol, Fischer-Tropsch diesel) can be "designed" to meet specified requirements in terms of their properties, starting from a synthesis gas that has been produced from solid biomass by means of thermo-chemical gasification. In this way, the fuel can be optimised for specific applications (e.g. engines, turbines). However, despite some promising early results, the development of appropriate commercially available processes and methods is still generally at an early stage. Moreover, to achieve the economies of scale necessary for commercial viability, the output of such plants needs to be in the order of several hundred to thousand of megawatts – depending on the type of fuel being produced – which raises new challenges with respect to biomass logistics.

Trends

► **Domestic heating furnaces**. There is a distinct trend towards high-efficiency, low-emission systems for generating heat from solid biofuels such as wood logs, wood chips and wood pellets. Emissions of particulate matter – an issue accorded a high priority on the political agenda these days – can be minimised by selecting the type of furnace best adapted to the solid biofuel in question. Additionally, the implementation of appropriate primary (i.e. related to the combustion unit) and secondary measures (i.e. flue gas treatment) might be necessary; for example, low-cost filters for removing particulate matter emissions from the flue gas of small-scale combustion units are already available on the market. It is also important that users should respect the prescribed operating conditions issued by the company producing the combustion device (i.e. by not misappropriating the heating furnace to burn household waste). The new types of condensing furnaces or boilers are likely to become more widespread in the years to come, because in addition to an improved overall efficiency they also feature significantly reduced pollution (i.e. emissions of particulate matter). It is also possible that systems designed for the combined generation of power and heat (e.g. based on the Stirling engine), especially for small-scale domestic applications, might one day become more common, although this is an area of power engineering that still needs intensive research.

► **Biogas production and utilisation**. In the industrialised nations, there is a tendency towards building higher-output biogas generation plants to process organic waste or energy crops. The main technological challenge, which has still not been satisfactorily resolved, is that of controlling and steering the *anaerobic digestion process* – and hence the production of biogas – in such a way that the output remains stable on a high level and predictable even when using a broad variety of input substrates. If this problem can be resolved, such plants will be able to ensure a reliable and highly efficient supply of high-quality biogas. One problem in this respect is that the bacteria responsible for the anaerobic digestion process react highly sensitively to changes in the properties of the substrate. There is therefore a need for a microbiology that is more tolerant of fluctuations in substrate quality, while at the same time breaking down the biomass to methane and carbon dioxide faster and more completely. For the input materials, operators are turning towards the use of waste streams – preferably monosubstrates – that in the past have only been used occasionally or not at all. There is also a growing trend towards the use of deliberately cultivated renewable resources, which are constantly being optimised by breeding varieties with improved biodegradability and significantly higher yields. Increasing quantities of refined biogas are also being fed into the natural gas distribution network, because this represents a very flexible and highly efficient means of making the gas available for use in numerous applications, including transportation. New methods of upgrading biogas to biomethane that meets natural gas quality standards will enter the market in the years to come. They include processes based on CO_2 removal with pressurised water or amines, or alternatively pressure swing absorption. Other methods (e.g. using *membrane* filters) are currently being tested. Although such methods have been in use for many years in the industrial processing of natural gas, there is still potential for improvement in plants operating at capacity ranges typical for biogas plants, which needs to be harnessed in the years to come.

In developing and newly industrialising countries, there is a trend towards the use of extremely simple biogas plants in which organic farming and household waste can be fermented to produce energy (i.e. biogas) and also provide valuable nitrogen fertiliser as a by-product.

► **Biofuels**. There is a need for industrial plants capable of converting biomass more efficiently into bioethanol. At the same time, there is growing political pressure to make more extensive use in the future of lignocellulosic biomass (i.e. biomass from plants or parts of plants that are not suitable for use as food). This explains the trend towards the development of integrated biorefineries. In such fully integrated biomass conversion systems, a wide range of different types of biomass are used to produce different types of fuel and other feedstock products (e.g. platform chemicals) with the least possible output of waste. This is true for processes based on bio-chemical biomass. In parallel, more advanced thermo-chemical processes are being developed that are designed to transform solid biomass into a synthesis gas (i.e. mixture of carbon monoxide and hydrogen) which can then be converted by various routes into gaseous (e.g. biomethane or Bio-SNG, hydrogen) or liquid fuel (e.g. Fischer-Tropsch diesel, DME). The latest biorefinery concepts aspire to a promising combination of bio-chemical and thermo-chemical processes.

Prospects

- Biomass can be converted into final or usable energy through a multiplicity of more or less complex supply chains – and hence using a wide variety of technical processes. This makes biomass a highly flexible renewable energy source.
- The use of solid biofuels for the provision of heat for cooking and heating purposes is the most important application from a global point of view. This explains why biomass currently contributes most to covering the given energy demand compared to all other renewable sources of energy.
- As energy prices continue to fluctuate widely at short notice, it can be expected that the demand for biomass-based energy solutions will increase across all markets. Consequently, there is an urgent need for new processes and techniques that will ensure high conversion efficiency, low energy provision cost, a significantly reduced environmental impact, and clearly defined specifications of the provided energy carrier to ensure that the biofuels or bioenergy fits easily into the given structures within the existing energy system.
- Given that the generation of energy from biomass will always have to compete with other forms of land use, dedicated to the production of food, fodder and industrial feedstock, it is vital that measures should also be taken to increase the productivity of agricultural and forestry land through the provision of improved seed material and better management schemes.

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Internet

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